FINAL REPORT
COOPERATIVE AGREEMENT BETWEEN US FOREST SERVICE AND BRIGHAM YOUNG UNIVERSITY: WILDLIFE MANAGEMENT STUDY (OAK)

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by

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CONTENTS

In this report, I have responded item-by-item to the objectives of the Cooperative Agreement. Those objectives are reproduced in full below.

1. <u>Overall Objective</u>

   To develop an efficient Gambel oak management plan for wildlife habitat improvement on the Uinta National Forest, with special emphasis on big game winter ranges.

2. <u>Segment Objectives</u>

   a. To complete an intensive review of the literature pertaining to Gambel oak management in the Western states.

   b. To map the Gambel oak vegetative types or associations on the Uinta National Forest.

   c. To review the literature relating to the successional dynamics of Gambel oak in relation to ecological and physical parameters such as elevation, slope, aspect, soils, and use by ungulates. Also, what factors limit the range of Gambel oak, i.e., why does the oakbrush-type end shortly east of the Uinta National Forest and not extend into the Uinta Basin?

   d. To determine or evaluate wildlife use of Gambel oak as compared to use of other vegetation types, with regard to both ecological and physical parameters, including heights and densities of stands.

   e. To determine how Gambel oak can most effectively and economically be managed in order to provide optimum habitat conditions for selected species of wildlife.

f. To develop an efficient, long-term or rotational Gambel oak management plan for wildlife habitat on the Uinta National Forest, emphasizing big game winter ranges. The plan also should present detailed information in a format that can be readily adapted to fulfill the requirements of an Environmental Impact Statement (EIS) or an Environmental Assessment Report (EAR).

I will respond first to items listed under heading 2. Segment Objectives, since each segment is part of the overall objective outlined under heading 1 above.

Item 2a. Literature Review.

A copy of the literature review is attached to this report. The review is current to January 1, 1984. A total of 226 papers relevant to the biology and management of *Quercus gambelii* Nutt. are treated in the review. Our search of libraries at Brigham Young University and University of California, Berkeley, and of U.S. Forest Service files shows that the review includes all substantive published reports on the species. The final manuscript (double spaced typing) is in excess of 90 pages. It has been accepted for publication as a Research Paper by the Intermountain Forest and Range Experiment Station, Ogden, Utah, and should appear late in 1984. The review integrates and discusses the literature pertaining to distribution and ecology of Gambel oak relative to climate, soils, and elevation. Reproductive biology, natural pests, and tissue chemistry of the species are reviewed. Special attention is

given to the species' response to grazing animals (native and domestic), fire, herbicides, and various mechanical management treatments.

Item 1b. Mapping of oak on the Uinta National Forest.

As noted as a possibility in the original agreement, the Uinta National Forest has completed this portion of the project. Their mapping results have been reduced to digitized format and stored in a form accessible to Forest Service personnel through agency computer terminals. Data on oak are extractable by Ranger District and, within Districts, by vegetative type, slope steepness, elevation, and proximity to roads.

Item 2c. Review literature relative to successional processes in oakbrush communities and factors controlling the geographical distribution of Gambel oak.

Item 2C, Literature Review of Succession in Oak Communities

Successional Dynamics

Successional trends in Gambel oak communities may lead to suppression of oak by big tooth maple (*Acer grandidentatum*), white fir (*Abies concolor*), ponderosa pine (*Pinus ponderosa*) or Rocky Mountain juniper (*Juniperus scopulorum*) (Dixon 1935, Hayward 1948, McKell 1950, Allman 1953, Christensen 1950, 1958, Nixon and Christensen 1959, Nixon 1961 and 1967, Cronquist and others 1972 and Steinhoff 1978). Dixon (1935) suggested that in most areas, oak is an ecological equivalent to ponderosa pine, but in such areas as the Aquarius Plateau of central

Utah, it appears to be pioneer to the pines. Brown (1958) considered oak to be a climax species, but Cronquist and others (1972) suggested that it is subclimax to ponderosa pine. In all probability, oak forms climax cover on some sites, but on many others there is unequivocal evidence that it is seral. Several authors have presented evidence that maple is invading oak stands and will eventually replace them (Allman 1952, 1953, Nixon and Christensen 1959, Nixon 1961, 1967, Eastmond 1968, and Eastmond and Christensen 1968). Christensen (1964) believed that oak stands on steep, north-facing slopes in Provo Canyon, Utah, were moving toward dominance by a mixture of white fir and Douglas fir.

Allman (1952, 1953) and McKell (1950) concluded that fire killed aboveground oak stems, but not roots and rhizomes. Oak sprouts prolifically after fire, producing a denser stand than occurred before burning (McKell 1950 and Allman 1952, 1953). After 18 years, both Allman and McKell considered that an oak stand would have essentially the same structure as before the fire. Brown (1958) and McKell (1950) showed that oak thickets were dense when young but thinned out as the stands matured.

Hallisey and Wood (1976), working in Pennsylvania reported that burning did not eliminate plant species initially existing in oak stands nor enhance invasion of new species. In Utah, however, late successional woody species appear to be more vulnerable to fire than oak itself. Kunzler and others (1981) showed that even in early and midsuccessional stages of oak stands in central Utah, fire exerts a conspicuous influence on plant composition in the herb layer: annual species increased after fire while several perennial herbs decreased. Nevertheless, the compositional impacts of fire in the oak type of Utah

seemed to disappear in less than 20 years (McKell 1950, Kunzler and others 1981).

In the southern portion of its range, Gambel oak often forms open stands of small, competition-suppressed plants under ponderosa pine forest canopies. Should the pine be removed from such stands by fire or logging, oak often becomes dominant (Pearl 1965, Dick-Peddie and Moir 1970). Reestablishment of pine on sites thus stocked with oak is difficult. Herman Ball (cited in Steinhoff 1981) estimated that over half the area potentially available for commercial growth of ponderosa pine had been taken over by oak on the San Juan National Forest of Colorado. Steinhoff (1981) considered that repeated light fires would reduce oak vigor and permit ponderosa pine reproduction to regain control of such sites. Hot fires eliminated pine and left oak in control of the site.

Studies are rare in which observers have recorded community traits as Gambel oak has been displaced as stand dominant by any other woody species. Eastmond (1968) summarized his own observations and those of two others (Allman 1952 and Nixon 1961 and 1967) of an oak stand in central Utah that was being invaded by bigtooth maple. One can also draw some inferences about likely changes associated with natural succession from analysis of stands dominated by oak or a potential replacement species on comparable sites and in the same geographic area. In Table 1, an attempt is made to predict the direction of change in several community characteristics as oak is displaced by ponderosa pine, white fir or bigtooth maple. Inferences for ponderosa pine are based on Steinhoff's (1978) data from southwestern Colorado. Conclusions about changes associated with displacement of oak by white fir were drawn from

Table 1. Likely changes in the plant community as Gambel oak is displaced by ponderosa pine, white fir or bigtooth maple in natural successions. Changes are inferred from literature descriptions of actual sites in process of succession or from comparison of descriptions of stands on comparable sites but dominated by oak or the displacing species. Changes are shown as increases (+), decreases (-) or no change (0) in the factor in question during succession. Apparent trends that are questionable for any reason are noted by a question mark.

	Factor								
Forest Type Displacing Oak	Understory Composition (%)			Total Understory Production	Floristic Richness of understory	Palatability of Displacing Species[4]	Value as Escape Cover for Deer	Lumber Production	Fire Proneness
	Shrubs	Graminoids	Forbs						
Ponderosa pine[1]	0	-	0	-	0	-	+	+	+
White fir[2]	-	-	+	-	0	-	+	+	+
Bigtooth Maple[3]	-	0?	+	-	+?[5]	-	-	+?[6]	-

1. Inferred from comparison of averages for Steinhoff's (1978) ponderosa pine-oak association.
2. From Ream (1963).
3. Based on Eastmond (1968) and Kunzler and others (1981).
4. Based on use by deer in all seasons as gleaned from literature by Kufeld and others (1973).
5. Eastmond (1968) shows a large increase in numbers of understory species per quadrat over a 19 year period in which maple rapidly increased in a stand originally dominated by oak, but the stand had been heavily grazed prior to the 19 year period and was ungrazed during that period. Thus separation of grazing and successional processes as causes for the increase in floristic richness is not possible.
6. Based on rates of increases in oak and maple basal area in Eastmond's (1968) study and on observations by Christensen (1958).

analysis of data presented by Ream (1963) and unpublished data of our own. Consequences of bigtooth maple's invasion of oak stands were inferred from studies by Ream (1963), Eastmond (1968) and Kunzler and others (1981).

Available data suggest that many changes resulting from natural succession in Gambel oak stands will be the same whether the invading species is ponderosa pine, white fir or bigtooth maple (Table 1). In all cases, understory production will probably decline and the new canopy dominant will be less palatable to deer than was oak (Kufeld and others 1973). Likewise, all three of the invading species are likely to be more productive of marketable lumber than oak. Reduced production in the understory is expected because the replacement species are either evergreens (the conifers) that continuously shade the forest floor or, in the case of maple, leaf out several days before oak (Eastmond 1968). The downward trend in understory production will also be abetted by accumulation of deep litter layers under both conifer species. The fact that maple leafs out earlier than oaks and at a time when soil water is readily available and temperature and light conditions are ideal for understory growth (if there is little or no canopy cover) leads us to conclude that understory production will decline as oak stands are invaded by maple. Greater productivity of the invading trees themselves is at least partially attributable to the fact that they bear evergreen foliage or (in the case of maple) foliage on more days when soil moisture is abundant. Although oak leaves remain green longer than maple leaves in the fall, that is usually a period when soils are dry.

The data suggest that composition in the understory (relative forage production attributable to shrubs, grasses and forbs) will

probably show slight increases in relative importance of forbs and declines in relative importants of shrubs and grasses (Table 1). In any event, large changes in composition are not likely. Floristic richness in the understory is expected to decline where conifers displace oak, but trends in richness may be upward when the invading species is maple (Eastmond 1968 and Ream 1963).

Evergreen foliage and a tendency to retain basal branches for long periods make conifers superior escape-cover for large animals. Maple, on the other hand, may prove to be poorer escape-cover than oak, because of early defoliation in the autumn and a strong tendency to form dense, self-pruning stands. Resinous foliage and heavy litter layers will render stands invaded by conifer progressively more fire-prone. Maple stands, however, will probably be less prone to burn than the original oak stands, since maple foliage decomposes more rapidly than either that of oak or the conifers. Reduced growth in the understory of maple will also reduce the supply of potential fuel.

Successions in which oak is invaded and displaced as the dominant by ponderosa pine are apparently common in Arizona, New Mexico, southwestern Colorado and southeastern Utah in the upper half of the altitudinal range of oak (Dixon 1935). Bigtooth maple is probably the commonest tree to invade oak in Utah and northern Arizona, but that species is apparently present only locally on the western slope of the Rockies in Colorado (Little 1976). Bigtooth maple invades first along streams, bases of slopes and intermittent drainages throughout all but the highest elevation stands of oak. During the last quarter century, bigtooth maple has appeared on upland sites between drainages in central and northern Utah; there maple is now overtopping and gradually

displacing oak. Apparently, bigtooth maple is adapted to a broader array of sites than prior workers believed. Most general descriptions of the ecology of the species have described it as growing on banks of streams or along water courses (Tidestrom 1925, Sargent 1926, Davis 1952). Ecological descriptions of the vegetation of the Gambel oak zone of Utah written in the 1925-45 period make no mention of bigtooth maple (Sampson 1925, Dixon 1935, Cottam and Evans 1945). Considering the showiness of maple in autumn color, its omission from previous descriptions of the oak zone is unexpected and suggests that the current prominence of maple on open slopes in the foothills of Utah mountains is a comparatively recent occurrence.

Attempts to explain the recent surge in prominence of maple in the oak zone of this region generate no fully satisfactory explanations. One is tempted to explain the observations in terms of better control of brush fires in the oak zone during the past half century. Fires could be expected to be both more frequent and more intense on drier sites. It is known, however, that maple does sprout at least occasionally after fire in central Utah. Unfortunately there appear to be no observations on either the relative frequency of fire along drainage ways and on adjacent open slopes in our area nor on the relative frequency and vigor of maple sprouting after fire on such contrasting sites.

White fir invasions are to be expected only on cooler sites in the upper half of the elevational range of oak (Lull and Ellison 1950). On some such sites, bigtooth maple may precede white fir as a seral species, thus producing a longer and more complicated successional sequence. Portions of the stand studied by Eastmond (1968) had shifted from oak to maple dominance during the 19 years of study, but the steady

increase in frequency of white fir seedlings in the understory suggests that another cycle of displacement of the canopy dominant may be ahead. Eastmond (1968) felt that the white fir reproductions would not persist on the site, but he presented no evidence of fir mortality.

Rocky Mountain juniper is often a persistent member of ponderosa stands and reproduces with some regularity there (personal communication, Hayle Buchanan). In central Utah and northwestern Colorado, ponderosa pine is essentially absent, being found only occasionally and then only as scattered individuals or small groves. In that area, Rocky Mountain juniper is still present and may become an important invader of oak stands (Lull and Ellison 1950). No published studies of such successional situations were found, however.

Item 2c. Controls on Oak Distribution

Geographic Range of Oak

Gambel oak occurs within the ponderosa pine zone (lower transition zone in the Merriam system) of the Central Rocky Mountain Region of western North America (Figure 1; Dayton 1931, Cottam and others 1959, Little 1971). Present distribution of the species runs from northern Utah (Brigham City area) south through the mountains of Arizona and into northern Mexico. In the east-west direction, Gambel oak extends across central and southern Utah, appears in isolated populations on the Charleston Mountains of southern Nevada and is common across all but the southwestern corner of Arizona. The species is found throughout all except the southeastern portion of New Mexico and in isolated pockets in western Texas. In Colorado, Gambel oak occurs in all of the mountains

except the Front Range of the Rockies. It enters southcentral Wyoming in Carbon County. In Utah, the species is unexpectedly absent from all but the western and southern edges of the Uinta Basin and from most of the Uinta Mountains (present on calcareous rocks and alluvial sediments of both the western and eastern ends of the range) (Graham 1937, Hayward 1948, Christensen 1949, Clokey 1951, Allman 1952, Ream 1960 and 1963, Wells 1960, Grover and others 1970, Reynolds and others 1970, Little 1976a, and Steinhoff 1981). Allman (1952) and Mason and West (1970) indicate that areas dominated by Gambel oak are subject to recurrent wildfires.

The absolute elevational range of Gambel oak is between 3,250 and 10,200 ft (991 and 3,109 m) (Sampson 1925, Dayton 1931, Graham 1937, Hayward 1948, Baker 1949, Christensen 1949 and 1950, Allman 1952 and 1953, Cottam and others 1959, Ream 1963, Reynolds and others 1970, Horton 1975 and Steinhoff 1981). The elevational range limits are widest in the southern portions of the species range and become progressively narrower as one moves north (Neilson and Wullstein 1983). Steinhoff (1981) considered the optimal elevational range to be 7,100 to 9,000 ft (2,164 to 2,743 m) in southwestern Colorado. In northern Utah, stands of the species are best developed between 5,500 and 7,500 ft (1,676 and 2,286 m). Geographical distribution of the species appears to have been rather stable for several hundred years (Brown 1958), although some recent movement toward lower elevations in northern and central Utah has been reported by Christensen (1949 and 1950) and Rogers (1982).

Climatic Relationships

Oakbrush populations commonly experience a yearly temperature range of over 100°F (47°C) (Price and Evans 1937). The species commonly occurs in areas that experience freezing temperatures and a mean annual temperature of between 45 and 50°F (7.2 and 10°C). In central Utah, longterm averages show 90 frost free days per year in the oakbrush zone (Price and Evans 1937). Precipitation within the oak zone varies between 15 and 22 in (38 and 55 cm) per year. In the northern part of the species' range, summers are usually dry with occasional small thunderstorms (Baker and Korstian 1931, Price 1938, Lull and Ellison 1950, Allman 1952, 1953, Christensen 1959, and Eastmond 1968). Summer precipitation is more abundant in southern parts of the range: the amount of summer rainfall tends to decline steadily with increasing latitude (Neilson and Wullstein 1983).

Grover and others (1970) described Gambel oak as a good indicator of climatic conditions, because it does not occur in areas that receive less than 10 in (25 cm) of precipitation or where subfreezing temperatures exist over long periods of time. Christensen (1955) suggested that short growing seasons at higher elevations are the limiting factor for upward movement of oak. Cottam and others (1959) and Erdman (1961) concluded that occasional minimum temperatures which exceed the tolerance limits of the species determine the northern limits of oakbrush. Neilson and Wullstein (1983) presented good evidence that deficient summer precipitation combined with frequency and intensity of spring frosts limit the species' range in the north.

Soil Relationships

Studies suggest that most of the soils within the oakbrush zone are derived from limestone, limey sandstones and shales or granitic parent materials (Baker and Korstian 1931, Markham 1939, Allman 1952 and 1953, Nixon 1961 and 1967, Ream 1963, and Tew 1966, 1967, and 1969 and Steinhoff 1978). In southwestern Colorado, oak most often occurs on Argic Pachic Cryoboroll and Argic Cryoboroll soils (Steinhoff 1981). Soil texture under oak ranges from loams to silt loams. Soil moisture holding capacity is high because of an abundance of silts and clays and an organic content of 5.0 to 7.5 percent: pH ranges from 5.9 to 8.0 with most readings being circumneutral under oakbrush (Baker and Korstian 1931, Price 1938, Allman 1953, Nixon 1967 and Steinhoff 1981). Jefferies (1965a), Tew (1966, 1967, and 1969), Johnston and others (1969), Marquiss (1972) and Marquiss and others (1971) reported that soil moisture depletion is reduced when Gambel oak is eliminated from a site, but herbaceous understory is left intact.

Steinhoff (1978) showed that Gambel oak is more tolerant of heavy clay soils or heavy clay horizons within the rooting zone than pines or junipers. In Colorado, serviceberry is usually an important associated species with oak on heavier textured soils.

Factors Affecting Oak Distribution

In the northern parts of its range, the species appears to reproduce rarely from acorns (Christensen 1949, Muller 1951, Neilson and Wullstein 1983), but in the southern portion of its range where summer rains are heavier and more reliable, seedlings are more common (Neilson and Wullstein 1980a, 1983). Nevertheless, Rogers' (1982) photopairs do show some new oak plants that are apparently of seedling origin

throughout the species' range in northern Utah. Neilson (1981) also observed seedlings in northern Utah. In contrast, the species is a vigorous vegetative reproducer. Reproduction is usually from slow growing, freely-branched rhizomes that give rise to a multitude of sparsely branched shoots (Muller 1951). Spread of established clones currently appears to be slow in both Utah (Christensen 1955) and Colorado (Brown 1958).

Clonal growth of the species has implications for its maintenance in marginal environments and under conditions of intense competition. Clonal growth also insures great longevity of individuals and consequent slowing of the evolutionary rate (Muller 1951).

The species appears to occupy new locations by way of long distance transport of acorns by such agents as bandtailed pigeons, California Jays, Stellar Jays, or Lewis and California Woodpeckers (Christensen 1949, Pederson 1975 and Harper and others 1978). The Clark's Nutcracker has been observed to move bristlecone pine seeds over 13 mile (31.7 km) in a single flight (Vander Wall and Balda 1977). It is not inconceivable that Jays and Band-tailed Pigeons occasionally move acorns a similar distance. Less distant dispersal is regularly effected by small mammals, such as the Utah rock squirrel (Rasmussen 1941). Once attained, the new territory is tenaciously held by vegetative reproduction (Christensen 1949 and Brown 1958). Individual stems produced by vegetative reproduction remain attached to parental plants for long periods (Pendleton 1952).

Christensen (1957) and Rogers (1982) used historic photographs to document recent (that is since 1917 and 1940, respectively, for Christensen and Rogers) establishment of new oak clones and expansion of

previously established clumps. Rogers (1982) considered that the increase in oak clones on the eastern rim of the Great Basin has been especially rapid since 1940, but he acknowledges that his estimates might be off by as much as 30 years due to the difficulty of detecting oak seedlings less than a foot tall in photographic records of landscapes. Similarly, Petersen (1954) showed that oak had increased its cover between 1939 and 1953 on Morris Watershed in Farmington Canyon in northern Utah. Christensen (1955) noted that the rate of expansion of oak clones in northern Utah averaged from 1.5 to 12 in (3.8 to 30.5 cm) per year with about 4 in (10 cm) being typical.

As previously noted, Gambel oak is severely damaged by late season frost. Although the species is often found above 8,000 ft (2438 m) elevation in northern Utah (Allan 1962, Ream 1963, Crowther and Harper 1965) and above 9,000 ft (2743 m) in southern Utah (Christensen 1950), its continued existence there seems to be related to the insulating effects of deep snow in the winter and delayed flowering in the spring (Allan 1962, Neilson and Wullstein 1980b). At higher elevations, Allan (1962) reported that the species seems not to produce viable seeds. Allan (1962) believed that oak reached the higher elevations during the Altithermal interval of Antevs (1955). Normally, the species dominates an altitudinal belt above the pinyon-juniper zone and below the aspen or ponderosa pine zone (Markham 1939, Barger and Ffolloitt 1972).

Kunzler and Harper (1980) show that oak recovers from fire much faster at lower elevations and on warmer south-facing slopes. Barger and Ffolloitt (1972) reported that the species grew rapidly in both height and diameter early in life, but growth rates declined steadily with age.

Keddington (1970) has shown that water stress in Gambel oak increased as the season progressed, but was always least at the highest elevations sampled; as expected, plants showed maximum stress at the end of warm sunny days. Keddington (1970) concluded that moisture stress could not control the upper elevational limits of oak, since stress decreased with elevation. Nevertheless, the smallest and least vigorous oak plants studied by him occurred at the station highest in elevation. Neilson and Wullstein (1983) showed that in northern Utah most mortality of oak seedlings experimentally planted into natural stands of the species occurred in summer, not winter. Of the winter mortality observed, most was at higher elevations, but summer mortality was heaviest at the lowest elevations considered. Nevertheless, summer mortality was high (always over 30 percent) even at the upper elevational limits naturally achieved by the species. On open microsites (without canopy shading), mortality of seedlings was 100 percent at upper elevational sites: under canopy protection, some 60 percent of the seedlings survived the summer season at higher elevations. Neilson and Wullstein (1983) considered that summer mortality was usually induced by desiccation, while winter losses were most closely linked with spring frosts. Thus Neilson and Wullstein (1983) offer strong empirical support for Keddington (1970) and Christensen's (1949) conclusion that oak is limited at lower elevations by water stress and at higher elevations by competition, cold temperature, wind, and shorter growing seasons. Keddington (1970) noted that when Gambel oak and bigtooth maple grow in close association, "oak is better able to withstand a lack of surface soil moisture than maple."

Dina (1970) and Dina and others (1973) also reported on the pattern of water potential in Gambel oak stems. Dina (1970) and Dina and Klikoff (1973) found that neither net photosynthesis nor dark respiration rates of oak or bigtooth maple were much influenced by water stress. They found that both species responded so much alike in that respect that differences in carbon metabolism could not be the reason for their differences in distribution in the field. Oak is, however, distinctly less tolerant of shade than bigtooth maple (Christensen 1958). In contrast to Gambel oak and bigtooth maple, both net photosynthesis and dark respiration rates declined precipitously with increased moisture stress in boxelder maple (*Acer negundo*) (Dina and Klikoff 1973). Dina and others (1973) showed that both oak and bigtooth maple tended to be less water stressed at high than at low elevations. They also note that *Berberis repens*, a common understory associate in oak stands, showed no significant trend in moisture potential along an altitudinal gradient. The latter observation helps explain Neilson and Wullstein's (1983) observation that oak seedlings showed less summer mortality under the canopy of established oaks than in adjacent openings along an altitudianl gradient. An overstory of vegetative cover apparently ameliorates water stress of understory plants.

Neilson and Wullstein (1979, 1983) noted that Gambel oak seedlings rarely survived (80 percent mortality) in the northwestern portion of the species' range, but seedling survival is more common in New Mexico and Arizona where summer precipitation is common. They concluded that the northern range limit of the species is controlled more by summer drought than winter cold as some had concluded earlier (Cottam and others 1959). Neilson and Wullstein (1983) considered that drier

summers on the northern edge of the species' range rendered areas below 5,000 ft (1524 m) uninhabitable for the species. At the same time, declining temperatures and more frequent late spring frosts in the north largely eliminated oak from terrain above 8,500 ft. They showed that mortality of Gambel oak seedlings was far more dependent on moderate microsites (understory positions) on the northern than the southern edge of its range. As the northern edge of the range of oak was approached, increasingly more inhospitable conditions on both the lower and upper elevational limits confined the species to a progressively narrower elevational zone within which there were fewer microsites capable of supporting seedlings (Neilson and Wullstein 1983). The combination of a narrower exploitable elevational zone and fewer "safe" sites for reproduction within that zone was apparently adequate to halt the northward migration of Gambel oak.

Item 2d. Wildlife use of Gambel oak

<u>Wildlife Use</u>

Oakbrush communities provide valuable big game winter range for wildlife in Arizona (Russo 1964), Utah (Plummer and others 1968), and Colorado (Steinhoff 1978). Perry (1980) estimated that Gambel oak contributed as much as 75 percent of the available forage in winter on foothills of the Wasatch Mountains in Utah County, Utah. Since big game populations are often limited by the availability and condition of their winter range (Kufeld 1970a), oakbrush ranges have a significant affect on big game ecology. Russo (1964) suggested that oakbrush ranges are used lightly in winters with heavy snowfall, but heavily in light winters. Experience in central Utah has shown that decades of wildfire suppression have pushed much of the browse of Gambel oak out of reach of

wintering big game. Opening of "browseways" and small clearings with chainsaws in dense, decadent oak stands resulted in a 3-fold increase in usable forage and a 14 fold increase in deer use (Perry 1981).

In northern Utah, Smith (1950, 1953) and Smith and Hubbard (1954) studied feeding habits of deer on native browse and herbaceous forage species. Among the browse species, Gambel oak ranked anywhere from seventh (Smith 1950) to first (Smith and Hubbard 1954) in terms of the amounts consumed and the amount of time big game spent in stands of each species. Smith (1952) listed Gambel oak among the top 10 browse species on the Fishlake National Forest. Reynolds and others (1970) listed several wildlife species including deer, elk, turkeys, and squirrels which utilize Gambel oak for browse or mast.

Smith (1952) and Smith (1949) reported that the percent of oak utilized by deer varies with the availability of more favorable browse species. Kufeld (1973) ranked the plant species eaten by elk as highly valuable or least valuable; he ranked Gambel oak as highly valuable for winter and spring. Allman (1952) and Hayward (1948) also considered oak to be important cover for deer.

Wildlife Response to Management

Many researchers have reported an increase in use by deer and elk when areas are treated by fire, herbicides, or mechanical means to control Gambel oak (Price 1938, Anon. 1966, Patton 1969, and Plummer and others 1970). Steinhoff (1978) listed many species of wildlife found in oak associations (table 2) and rated then as tolerant or intolerant to several different types of treatments which will be discussed in more

detail later. The data show that of the bird species considered, 16 of 20 species (80 percent) prefer middle-to-late successional stages, 2 species (10 percent) show no preference for any particular stage, and the remaining 2 species prefer early successional stages. All of the foregoing bird species occur in Utah and seem to respond similarly here.

Of the mammalian species considered by Steinhoff (1978), 6 of 7 species (about 86 percent) preferred a seral stage midway along the successional sequence, while the other species (the Abert squirrel) was considered to prefer middle-to-late seral stages (Table 2). Elk and mule deer, species of central importance here in Utah, were both considered to prefer middle successional situations. The Abert squirrel does not occur in northern Utah and thus need not be considered in management plans for the Uinta National Forest. In total, Steinhoff's (1978) data suggest that if the management objective is to maintain maximum wildlife diversity and the largest possible big game herds, one should try to maintain most of the area of Gambel oak dominated habitat-types in stages midway along the successional sere. Late successional stages are preferred by less than half (45 percent) of the commoner bird species, while no major mammals prefer those stages of the oak types present in northern Utah (Table 2). Only 2 of the bird species (Scrub Jay and Band-tailed pigeon) considered to prefer late successional oak stands appear to be heavily dependent on that community type alone for survival. All other birds that preferred late seral stages of oak communities ranged widely and exploited a variety of other community types (Behle and Perry 1975). Accordingly there would appear to be no need to maintain large percentages of the Gambel oak communities in late seral stages. Maintenance of a small percentage of the total area of

Table 2. The distribution of selected animals that are at least seasonally influenced by a Gambel oak association. Three widely divergent plant associations in which Gambel oak is important are considered here. The occurrence of each animal species in each plant association is noted. The successional stage that an animal prefers in each plant association is also reported. Finally, the tolerance of each animal to severe perturbations of the community by fire, cutting, grazing, or herbicide treatment is estimated. The contents of this table are drawn from a report by H.W. Steinhoff (1978) which is based on that author's experience in southwestern Colorado.

Dependent Species	Zone of occurrence[1] PPO	OSO	PJO	Seral stage of best development	Disturbance[3] Fire	Cutting	Grazing	Herbicide
Aphelocoma spp. (Jays)		x	x	L	T	T	T	--
Chlorura chlorura (Green-tailed Towhee)	x	x	x	NP	T	T	T	--
Cyanocitta stelleri (Steller's jay)	x	x	x	L	T	T	--	--
Empidonax oberholseri (Flycatcher)	x	x		E-M	T	T	T	T
Meleagris gallopavo (Turkey)	x	x		NP	I	I	I	--
Sciurus aberti (Abert squirrel)	x			M-L	I	I	--	--
INFLUENCED SPECIES								
Bonasa umbellus (Ruffed Grouse)		x		M-L	--	--	--	--
Buteo regalis (Ferruginous Hawk)		x	x	L	I	I	I	I
Columbia fasciata (Band-tailed Pigeon)			x	L	--	--	--	--
Empidonax wrightii (Flycatcher)		x	x	L	T	--	T	--
Hylocichla guttata (Hermit Thrush)	x			M	I	I	I	--
Junco spp. (Junco)	x			M	T	T	--	--
Passerina amoena (Lazuli Bunting)		x		M	T	T	T	--
Phalaenoptilus nuttallii (Poorwill)		x		M	T	T	T	T

Table 2 continued.

<u>Pica</u> <u>pica</u> (Magpie)		x		L	--	T	--	--
<u>Salpinctes</u> <u>obsoletus</u> (Rock Wren)			x	M*	--	T	--	--
<u>Spinus</u> spp. (Goldfinch)	x	x		L	I	I	--	1
<u>Spizella</u> <u>passerina</u> (Sparrow)	x			M-L	T	T	--	--
<u>Vermivora</u> <u>celata</u> (Warbler)	x			L	T	T	--	--
<u>Vermivora</u> <u>virginiae</u> (Warbler)	x	x	x	L	T	--	I	--
<u>Zenaidura</u> <u>macroura</u> (Mourning Dove)	x	x	x	E	T	T	T	T
<u>Cervus</u> <u>canadensis</u> (Elk)	x	x	x	M	T	T	I	T
<u>Mustela</u> <u>erminea</u> (Ermine)	x	x	x	M*	T	T	--	T
<u>Mustela</u> <u>frenata</u> (Weasel)	x	x		M*	T	T	--	T
<u>Odocoileus</u> <u>hemionus</u> (Mule deer)	x	x	x	M	T	T	T	T
<u>Sylvilagus</u> <u>nuttallii</u> (Cottontail rabbit)	x	x	x	M	T	T	--	T
<u>Ursus</u> <u>americanus</u> (Black bear)	x			M	T	T	--	T

1. Zones of occurrence are: PPO, dense ponderosa pine-oak; OSO, oak-serviceberry-Oregon grape; PJO, pinyon-juniper-oak.
2. Seral stages are: E, early; M, medium; L, late; *, slight preferences for this zone; NP, no preference.
3. Animal tolerance classes are: T, tolerant; I, intolerant; -- more data needed.

oak in any local drainage area in late seral stages would probably be adequate to maintain healthy populations of all species considered in Table 2. It is also to be noted that one of the bird species considered in Table 2 to be dependent on late seral stages, the Band-tailed pigeon, rarely ranges as far north as the Uinta National Forest.

Major Wildlife Inhabitants

Some of the more common bird and mammal species that are found within the oakbrush zone are listed in table 3. Brotherson and others (1981) describe the bird community of oak stands in Navajo National Monument, northern Arizona. They contrasted the avian community of oak stands with that of several other plant communities in the Monument. They found many more bird species associated with mesic (such as oak on riparian edges) than xeric sites (such as juniper stands). The Scrub Jay, White-breasted Nuthatch, Common Flicker, Hairy Woodpecker, Mountain Chickadee and Rufous-sided Towhee were regularly observed in oak stands. The oak community had greater richness of bird species than pinyon-juniper woodlands adjacent to it. Black (1983) demonstrated that House Wren populations in the ponderosa pine - Gambel oak stands of southeastern Utah could be significantly enlarged by increasing the number of cavities for nesting. Most Gambel oak stands have few trees with natural cavities. Preservation of larger snag trees of any species in oak dominated sites would probably encourage larger Wren populations on more mesic sites and larger Bluebird populations on drier sites where oak grades into pinyon-juniper woodland (Brotherson and others 1981, Black 1983).

Table 3. Some common wild animals associated with Gambel oak stands in central and northern Utah. Data are primarily from Hayward (1948) and Behle and Perry (1975). Birds not otherwise designated are not yearlong residents of the area of concern.

Large Taxonomic Group and Species name	Common name	Subjective index of commonness
Reptiles		
Charina bottae[1]	Rubber boa snake	Common*
Hypsiglena torquata[1]	Night snake	Common*
Sceloporus graciosus[1]	Sagebrush lizard	Common
Thamnophis sirtalis[1]	Garter snake	Common
Birds		
Aphelocoma coerulescens[2]	Scrub Jay	Abundant*
Archilochus alexanderi	Black-chinned Hummingbird	Common
Carpodacus mexicanus	House Finch	Abundant
Chondestes grammacus	Lark Sparrow	Common
Chlorura chlorura	Green-tailed Towhee	Common
Cyanocitta stelleri[2]	Stellar's Jay	Common
Dendroica coronata	Yellow-rumped Warbler	Common
Dendroica petechia	Yellow Warbler	Common
Empidonax difficilis	Western Flycatcher	Common
Empidonax oberholseri	Dusky Flycatcher	Common
Molothrus ater	Brown-headed Cowbird	Common
Oporornis tolmiei	MacGillivray's Warbler	Common
Parus atricapillus[2]	Black-capped Chickadee	Abundant
Passerina amoena	Lazuli Bunting	Abundant
Pheucticus melanocephalus	Black-headed Grosbeak	Common
Pica pica[2]	Magpie	Common
Pipilo erythrophthalmus[2]	Rufous-sided Towhee	Abundant*
Pooecetes gramineus	Vesper sparrow	Common
Selasphorus platycercus	Broad-tailed Hummingbird	Abundant
Spinus pinus[2]	Pine Siskin	Common
Spizella passerina	Chipping Sparrow	Abundant
Sturnus vulgaris[2]	Starling	Common, introduced
Troglodytes aedon	House Wren	Common
Turdus migratorius	American Robin	abundant
Vermivora virginiae	Virginia Warbler	Common
Vireo gilvus	Warbling Vireo	Common
Mammals		
Canis latrans[2]	Coyote	Common
Cervus canadensis[2]	Elk	Common
Spermophilus variegatus[1]	Rock squirrel	Abundant
Clethrionomys gapperi[2]	Red-backed vole	Common
Erethizon dorsatum[2]	Porcupine	Common

Species name	Common name	Commonness
Eutamias dorsalis[1]	Cliff Chipmunk	Locally common
Eutamias minimus[1]	Least Chipmunk	Common
Eutamias quadrivitattus[1]	Colorado chipmunk	Common
Lynx rufus[2]	Bobcat	Common
Marmota flaviventris[1]	Marmot	Common
Mustela frenata[2]	Long-tailed Weasel	Common
Odocoileus hemionus[2]	Mule deer	Abundant
Peromyscus maniculatus[2]	Deer mouse	Very abundant
Peromyscus truei[2]	Pinon mouse	Locally common
Reithrodontomys megalotis[2]	Western harvest mouse	Locally common
Taxidea taxus[2]	Badger	Common

1. Winter hibernators
2. Yearlong residents

*Species heavily dependent on oak vegetative types.

In northern Utah, Marti (1977) found Blue-gray Gnatcatchers, Black-headed Grosbeaks, Lazuli Buntings and Rufous-sided Towhees to be the commonest nesting birds in oakbrush stands. Only 6 bird species were permanent residents at Marti's (1977) site: California Quail, Ring-neck Pheasant, Scrub Jay, Black-billed Magpie, Black-capped Chickadee and Rufous-sided Towhee.

Oak Chemistry and Forage Value

Tissue chemistry of Gambel oak has been studied by a few workers. Dayton (1931) reported that young shoots contained 4 to 10 percent tannic acids. Nastis and Malecheck (1981) found that immature terminal twigs with their leaves contained 11.1 percent tannin. In mature twigs, tannin content dropped to 8.7 percent. Dietz (1958) showed that Gambel oak leaves were relatively high in protein in late spring and late summer, but stems were always low in protein. Kufeld and others (1981) reported an average of 5.1 percent crude protein in Gambel oak twigs (current growth only and without leaves) in January: values were similar throughout Colorado. The same twigs averaged 27.8 percent soluble carbohydrate, 3.9 percent ether extract, and 4.7 percent ash (4.0 percent soluble ash). *In vitro* digestible dry matter of the twigs averaged 28.1 percent . By way of comparison, sagebrush (*Artemisia tridentata*) current year twigs (with leaves, no inflorescences) taken at the same time as the oak twigs just discussed had average contents of 9.9 percent crude protein, 43.2 percent soluble carbohydrate, 5.3 percent ether extract and 4.6 percent ash. *In vitro* digestibility of those sagebrush samples averaged 49.9 percent. Carotene content of the leaves is consistently high, but their crude fat level is low (Dietz

1958). Smith (1957) showed that in their leafless, winter condition, Gambel oak twigs are low in protein, ether extract, nitrogen free extract, and total digestible nutrients. The comparative summary of browse plant forage value by Welch and others (1983) shows Gambel oak to rank at or near the bottom of the list of species considered for total digestible nutrients, dry matter digestibility, and crude protein content. Engle and Bonham (1980) demonstrated that the nonstructural carbohydrate content of Gambel oak rhizomes from young sprouts was lowest midway through the leaf expansion process. Nonstructural carbohydrate levels in rhizomes of mature stems had been previously reported to be highest at the time when leaves reached maximum expansion (Marquiss 1968).

Toxic Properties

If abusive grazing pressure has eliminated associated species from Gambel oak stands, browsing animals may be forced to consume enough oak to produce sickness or death (Marsh and others 1919, Dayton 1931, Stoddart and others 1949, Muenscher 1957, USDA 1968). The plant is most dangerous in the spring when tannin concentrations are maximum (USDA 1968), but if animals are forced to consume enough of the plant, it is dangerous at any season (Muenscher 1957). Normally up to 50 percent of the diet can consist of oak without trouble; when oak contributes 50-70 percent of the diet, sickness almost always follows, and when oak makes up over 75 percent of the diet, death often results (USDA 1968). Toxicity is enhanced by freezing; young foliage turned black by frost is especially dangerous (Stoddart and others 1949). Leaves are the

principal sources of tannins, but acorns also can be dangerous (Muenscher 1957).

Apparently only cattle are in danger of oak poisoning (Stoddart and others 1949). Goats seem more tolerant of oak tannins than other domestic livestock, but even they show large fecal nitrogen losses when tannin intake is high (Nastis and Malecheck 1981). Symptoms of poisoning in cattle include gaunt, "tucked-up" appearance, constipation, emaciation, dark urine, and mucous and blood in feces followed by profuse diarrhea, weakness, unwillingness to follow the herd, and collapse (Marsh and others 1919, USDA 1968). The symptoms closely parallel those of cattle "summer sickness", an ailment long recognized on oak ranges in Utah (Marsh and others 1919).

Item 2d. Factors Affecting Wildlife Use of Oak Communities

The animals listed in Tables 2 and 3 include all the major species associated with oak communities in Utah. None of the species are confined to oak vegetational types and only a few occur in oak and but one or two other vegetational types. Such dependent species in central and northern Utah include the Scrub Jay, Green-tailed Towhee, Lazuli Bunting, Rufous-sided Towhee, and the Lynx (Behle and Perry 1975, Durrant 1952). Of the four reptiles listed in Table 3, all but the rubber boa are both geographically and ecologically widespread. The rubber boa is probably best represented near streams in the oak zone in our area, but it does range upward to the montane conifer zone (Stebbins 1966). The ermine weasel is rarely collected in Utah, but one of its few records here is from the oak zone at the head of Slate Canyon in the

Wasatch Mountains, Utah County (Brigham Young University mammal collection, Monte L. Bean Museum). Of those animals that are more dependent on oak habitat-types, the Lazuli Bunting, Rufous-sided Towhee, and the rubber boa also frequent riparian edge vegetation. It is also probably true that the lynx and the ermine spend more time in riparian vegetation than one might expect on the basis of area covered by that vegetative type alone. In fact, riparian strips through the oak zone undoubtedly have a strong enriching effect on species richness of all vertebrate groups. According, preservation of intact, minimally disturbed riparian strips should be an important consideration for all management decisions that affect the oak zone.

Item 2d of the objectives calls for a judgement concerning the effects of stem height and density on wildlife use of oak vegetation. Any definitive statement on this issue would entail far more basic research than the funding available for this contract would permit. Furthermore, I have found no references in the literature that directly address this question. One general relationship is perhaps inferable from ornithologist's work with the effects of foliage height diversity (i.e., how high is the canopy and is foliage of all species combined uniformly distributed from canopy top to ground layer?) on species richness and number of breeding bird pairs per unit area at a site. The relationship was shown to be strongly positive by MacArthur and MacArthur (1961) who developed the concept. Collins (1983) showed that the relationship is also statistically valid here in Utah. Thus as oak stands recover from a devastating fire, one would predict that there should tend to be more kinds of birds associated with the progressively taller stand provide that an understory of small shrubs and/or herbs was

maintained below the oak canopy. It will be recalled that Kunzler and Harper (1980) showed that original height would be reached again by oak within no more than 30 years after fire on even the sites of slowest recovery. Thus one might expect significant increase in richness of the avian fawna on oak burns during the first score of years after fire, but I know of no studies that document such a trend.

If one assumes that early post-fire oak stands are short and dense and that late (> 20 years) post-fire stands are taller and more open, some inferences relative to the impact of stem height and density may be drawn from Table 2 which is abstracted from Steinhoff's (1978) work in southwestern Colorado. Steinhoff noted whether specific animal species showed a preference for early, middle or late seral stages in various oak communities present in his area. He also reported whether or not those species were tolerant of fire and cutting (presumably clear-cutting or, at least, heavy cutting). One would expect both burned and clear-cut stands to sprout prolifically and produce a dense stand of oak stems that would rapidly grow taller for about 20 years. That expectation is apparently realized, since Steinhoff's (1978) data indicate that animal response to burning or cutting was similar in all cases where information was adequate to determine response of the species to both perturbations. I will assume in the absence of more specific information that species which are tolerant of burning or cutting will not be handicapped to any significant degree by those influences in the oak types considered by Steinhoff (1978).

Given the foregoing assumptions, it is seen (Table 2) that no wildlife species rated prefer early seral stands, but only three of the species on Steinhoff's list (17 bird and 5 mammal species) that also

occur in central and northern Utah were considered to be intolerant of the dense, low stature stands resulting from cutting or fire. Species judged to be intolerant of those early post-cut or post-fire conditions were all birds: Feruginous Hawk, Hermit Thrush, and Virginia's Warbler. Fortunately all three of the intolerant species have habitat preferences that extend well beyond the oak types (Behle and Perry 1975). The size of populations of such species should not be seriously affected even in individual drainages, if cuts or controlled burns are confined to small (less than 16.2 ha or 40 acres) areas in any one year.

I assume that the middle seral stages of Steinhoff (1978) are those in which natural thinning has eliminated many of the stems that initially spring up after fire (especially) or clear-cutting. In such stands, stems are not so thick as to impede movement of large animals nor so tall that the foliage is beyond the reach of big game browsers (2m or 6.5 ft). It seems likely that such midsuccessional conditions are always reached within 15-20 years in central Utah (McKell 1950, Kunzler and Harper 1980); on warmer, more fertile sites, that stage may be reached within a decade. Information is inadequate to predict a time range in which oak canopies are elevated beyond the reach of big game and new sprouts become too infrequent to provide a significant browse resource. Certainly the onset of late seral (when the canopy becomes unreachable by browsing vertabrates) stages will be highly variable, since high elevation sites always support short, scrubby oak with canopies that are never out of reach of big game animals (Allan 1962, Crowther and Harper 1965, Keddington 1970). Furthermore, many small stature stands also occur on harsh sites at low ($<$6,000 ft. or 1829 m) elevations, and recovery rates (height growth per year) rates differ

among stands by a factor of at least 5 (Kunzler and Harper 1980). Accordingly, few stands at any one time in a given drainage basin will have the bulk of their forage out of reach of browsers (especially big game which will browse to greater heights than sheep), if the management scheme has a return-for-treatment cycle of 50-75 years. Unpublished observations by Kunzler and Harper and by Fred Wagstaff indicate that volume increment of Gambel oak stems falls below 8% per year relative to initial volume between 50 and 60 years of age. That time interval is sufficient to produce stem diameters at breast height (4.5 ft or 1.37 m) of over 3.0 in (7.6 cm) for even slower growing stems on sites of average or better quality. Faster growing stems will reach diameters in excess of 8.0 in (20.3 cm) in 50 years (Wagstaff, personal communication). Accordingly, a 50-60 year cutting or burning cycle should keep foliage within reach of browsing animals, while providing stems large enough to be attractive to harvesters of fuelwood. That harvest cycle would also preclude the possibility of oak growth rates falling below a level at which the growth increment has a lower value than interest that would have accrued had the crop been harvested and the revenue invested (Figure 1).

Item 2 e. Management alternatives

Management

Only a few studies have evaluated management alternatives for the Gambel oak types. For sake of simplicity, management will be considered under three headings: fire, chemical (herbicides), and mechanical (such

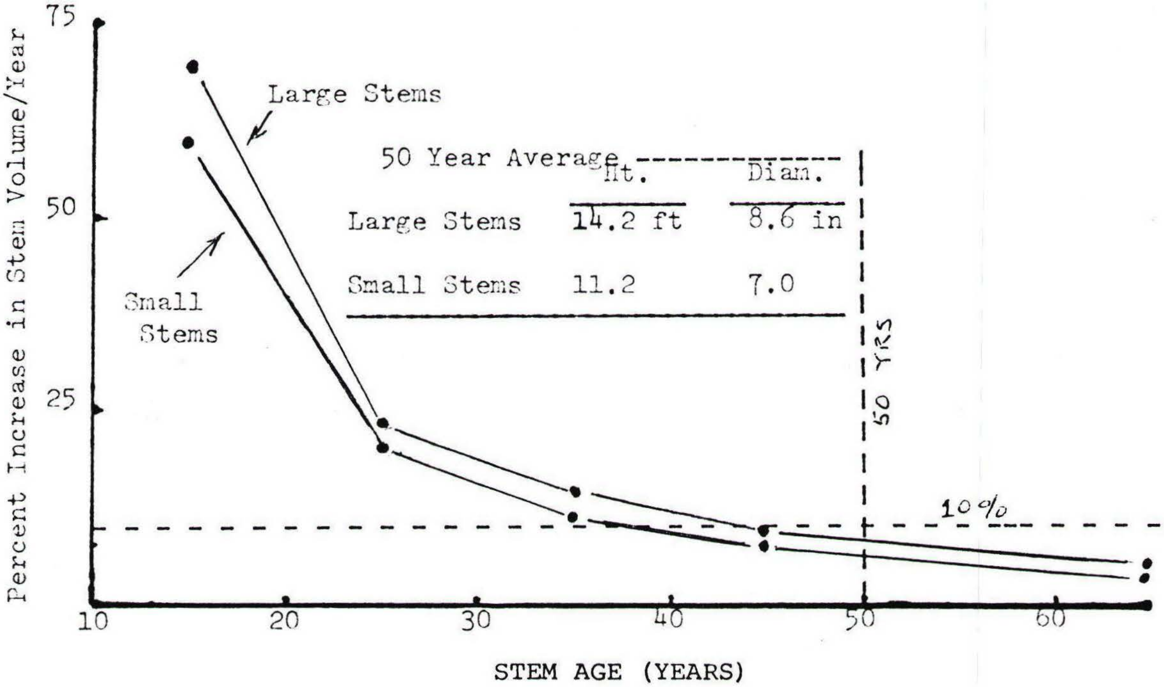

Figure 1. Percentage increase in stem volume per year. Results are averages for larger and smaller stems from 6 different sites (3 stems/size class/site). Assuming that capital can command 8.0% interest in the market place, it would be uneconomical to leave oak standing unharvested in central Utah after 50 years assuming this sample is representative of Gambel oak growth rates throughout the area (data from unpublished work by Fred Wagstaff).

as chaining, dozing, harrowing). Although complete protection also can be considered as a management technique for improvement of a site for forage production, the author considers it impractical because of the long time required to produce favorable results. Brown (1958), Eastmond (1968), Nixon (1961, 1967), and Thomas (1970) indicate that several decades may be required to demonstrate significant changes in the forage base in oak stands undergoing natural recovery. Cottam and Evans (1945) also consider the effects of exclosure of domestic grazers from the oak zones in northern Utah.

Fire

The most extensive studies on fire within the oakbrush zone were made by Baker (1949), who looked at soil changes, and McKell (1950), who studied the effect of fire on the vegetation itself.

Baker (1949) reported that after fire, pH of the soil increased by 0.1 to 0.7 units, and nitrogen, phosphorus, potassium, and soluble salts also increased, but soil moisture content was lower on burned areas, and there was less litter. The difference in soil organic content between burned and unburned areas was not statistically significant. Fire stimulated shoot growth.

McKell (1950) noted that fire stimulated shoot production of most shrub species that occur frequently with Gambel oak. He also found that most other plants increased in number following fire but, after 9 years, he found no significant difference in the number of oak stems per unit area on burns and adjacent unburned areas. After 18 years, the area had returned to nearly its original vegetation. He suggested that the loss of plant cover through burning had more serious implications for soil stability than it did for plant cover itself, since most of the plants

sprouted. Allman (1952) and Brown (1958) reported the fires are frequent in the oakbrush zone, but that fires killed only the stems of oak. Several shoots replaced each one destroyed by fire.

Although prolific sprouting occurs after burning, several authors have concluded that it can be minimized by seeding competitive grasses after fire (Frischknecht and Plummer 1955, Plummer and others 1966 and Plummer and others 1970). Nevertheless, my examination of the foregoing authors' study plots forces me to conclude that additional studies are needed before their results can be accepted as conclusive. Clearing oakbrush with fire is feasible, but if improved forage conditions are the objective, burned areas must acquire heavier covers of grasses and forbs than existed initially. A mixture of grass species is usually recommended for seeding on burned sites (U.S. Forest Service 1966, Plummer and others 1970), but the matter of suitable forbs for inclusion in seeding mixtures has received little research. Selection of suitable forbs for the oak zone merits further attention.

Smooth brome (*Bromus incrmis*, intermediate wheatgrass (*Agropyron intermedium*), and crested wheatgrass(*A. cristatum*) are frequently recommended for seeding into burned or chained oak stands (Anon. 1966, Plummer and others 1966, Plummer and others 1970). Intermediate wheatgrass, pubescent wheatgrass, quackgrass, meadow brome, and smooth brome have all been tried with success in central Utah (Frischknecht and others 1955). Plummer and others (1968) have also had success with mountain brome (*Bromus carinatus*), orchard grass (*Dactylis glomerata*), and tall oatgrass (*Arrhenatherum elatius*). Plummer and others (1968) list other species of grasses, forbs and shrubs that may be added to seeding mixtures for general and special purposes.

Steinhoff (1978) considered how various wildlife species could be expected to respond to various management treatments in the Gambel oak zone. He included burning as one treatment for consideration (table 2). Steinhoff (1978) considered that only the hermit thrush was intolerant to a cool burn in oak. About one-third of the species that were rated were listed as intolerant to a hot burn.

Dills (1970) considered that controlled burning provided more browse for deer by stimulating sprouting and permitting the penetration of more light to stimulate greater herbaceous growth. Evidence suggests that burning could be an effective and inexpensive tool for manipulation of oakbrush on deer ranges where a market does not exist for fuelwoods or where slopes are too steep to permit fuelwood harvest.

Current law requires that land managers limit the emission of air pollutants from prescribed burns (Sandberg and others 1979). Before prescribed fires are started, managers must have enough information in hand to demonstrate that standards will not be exceeded. This may necessitate some basic research to satisfy local regulations. Establishment of firelanes and maintenance of a fire crew to insure that controlled burns do not spread beyond the desired limits will increase costs, but are necessary.

Pearl (1965) is representative of some managers that consider that burning should be rejected as a control method for Gambel oak because of adverse effects on scenic, wildlife, soil, and economic values. Before fire is used as a management tool in the oak type, an attempt should be made to anticipate public response to it's use at specific locations.

Herbicides

Since the mid-1960s, a number of reports on response of Gambel oak to various herbicides have appeared. Early research centered on 2, 4, 5-T, 2, 4, 5-TP (Silvex), picloram (marketed alone or in mixtures with various phenoxy herbicides as Tordon) and mixtures' of any two of those chemicals. Initial experience demonstrated that Gambel oak was more resistant to herbicides than most plant species. Although all of the foregoing chemicals killed Gambel oak foliage, their effects were less lethal to stems and below-ground parts. Prolific sprouting occurred under at least some conditions after as many as three consecutive years of treatment of above-ground parts with the herbicides noted above (Heikes 1964, Jefferies 1965, Pearl 1965, Marquiss and Norris 1967, and Marquiss 1968, 1972, 1973). Field work showed that penetration was better and undesired drift was less when herbicides were applied in water-petroleum oil emulsions (Pearl 1965, Klingman and others 1982).

In the late 1960s and early 1970s work continued with 2, 4, 5-T, 2, 4, 5,-TP and picloram alone and in mixtures with phenoxy herbicides, while newer herbicides were also tested. Johnson and others (1969) and Reynolds (1970) reported that of numerous herbicide trials reported for control of Gambel oak in Arizona, only a few were even moderately successful in reducing crown cover for long periods; vigorous sprouting followed application of almost all herbicides considered. Crowns could be reliably killed by treating trunk frills and girdles with saturated solutions of AMS (ammonium sulfamate, commonly marketed as Ammate), but sprouts quickly appeared. Vallentine and Schwendiman (1973) found that AMS used as a basal spray without trunk frills was relatively ineffective against Gambel oak. Basal applications of the ester form of 2, 4, 5-T in diesel oil and soil application of pelleted fenuron (a

urea-type herbicide) in the dormant season reduced sprouting (Johnson and others 1969). Vallentine and Schwendiman (1973) confirmed those results for basal sprays with 2, 4, 5,-T. Marquiss (1973) applied 2.5 lb active ingredients (a.i.) (1.1 kg a.i./o.4 ha) of fenuron pellets to the soil, but found that dosage ineffective against mature oak.

Marquiss (1969) studied the effects of nonstructural carbohydrate reserves in oak rhizomes and roots at time of application on susceptibility to herbicides. He found that mature trees apparently did not begin to replenish root reserves until about the time that full leaf size was achieved (late June or early July) in southwestern Colorado. He concluded that sprouting was about equally vigorous whether herbicides were applied in the spring or in the summer (Marquiss 1973). Working with rhizomes of young sprouts, Engle and Bonham (1980) came to a somewhat different conclusion, namely that nonstructural carbohydrate content of rhizomes was lowest midway through the leaves expansion process. They felt that root kill would be enhanced, if herbicides were applied when root reserves were most depleted. The assumption was that herbicides were more likely to be translocated to rhizomes and roots when nonstructural carbohydrates were being moved from leaf to underground parts at rapid rates. Engle and Bonham (1980) found that applications of herbicides after root reserves were replenished gave excellent stem kill, but stem crowns sprouted immediately and produced such vigorous sprouts that root and rhizome food reserves equalled and often exceeded those of control plants by season's end. Their results suggest that herbicide ~~foliar~~ applications to Gambel oak foliage should be made well before leaf expansion is complete.

Marquiss (1971, 1972, 1973) demonstrated that phenoxy herbicides alone rarely gave over 50 percent stem kill after single applications at rates of up to 3.0 lb a.i/A; (1.36 kg/0.4 ha); sprouting was usually abundant even after multiple treatments. Silvex at 3.0 lb a.i/A (1.36 kg/0.4 ha) was more effective, giving as much as 80 percent control (Marguiss 1972), but picloram mixed with either phenoxy herbicides or silvex gave the best results for both stem kill and suppression of sprouting (Marquiss 1973). Bartel and others (1973) concluded that since Silvex-picloram mixtures gave good control over Gambel oak and were essentially nontoxic to established grasses (but not to dicotyledonous shrubs and forbs), enhanced forage production in oak understories might sometimes offset the costs of herbicides and make such treatments economically feasible range improvement practices. Vallentine and Schwendiman (1973) agreed that Silvex-picloram mixtures (1.2 lb a.i./A) applied to foliage caused heavy stem mortality and gave considerable control over sprouting, but they did not consider the treatment to be economically justified except for spot treatments where special needs warranted larger expenditures. The latter authors found picloram alone (4.0 lb a.i./A or 1.8 kg/0.4 ha applied to soil in granular form or as a basal spray at a rate of 8.0 lb a.i./100 gal or 3.6 kg/378 l) and 2, 4, 5-T (16.0 lb a.i./100 gal) as a basal spray gave nearly complete stem kill of oak and minimal sprouting. They also concluded that Bromacil (a uracil type compound) at 12 lb a.i./100 gal (5.4 kg/378 l) as a basal spray gave nearly complete kill but some stems took three years to die. They observed that Silvex, picloram and Bromacil were translocated through rhizomes in sufficient quantity to kill plants over 10 ft (3m) away.

Marquiss (1973) noted that the same herbicide treatment applied repeatedly gave "highly variable results from year to year". Thus managers should realize that treatment prescriptions must be adjusted to local conditions for best results.

Van Epps (1974) ran extensive herbicide trials on Gambel oak in Utah. He found that fenuron applied as granules at 8 lb a.i./A (3.6 kg/0.4 ha) in the spring gave nearly complete control of mature oak stems and subsequent sprouting. The herbicide continued to cause injury three and four years after application despite the fact that it is reported to remain active in soil for only 3-12 months (Klingman and others 1982). Apparently marginal amounts of precipitation at treatment sites failed to completely dissolve granules in the first two years after treatment. Fenuron was readily translocated through oak stems and caused injury to plants as much as 80 ft (24.4 m) from the point of application. That herbicide destroyed all understory growth (both monocots and dicots) in Van Epps' plots. Although fenuron gave better control over oak than any other tested (2, 4, 5-TP, picloram, and picloram mixed with 2, 4-D or 2, 4, 5-T in various proportions), Van Epps did not recommend it because of its persistent soil sterilizing effect.

Van Epps (1974) found that Tordon 225 (3:3 lb/A or 1.4:1.4 kg/0.4 ha mixture of picloram and 2, 4, 5-T applied as foliar spray) consistently gave good control of mature oak stems (average of 87 percent reduction of canopy) and subsequent sprouting (average of 57 percent injury on sprouts) without harming grasses in the understory. Tordon 212 (3:6 lb/A or 1:4:1.8 kg/0.4 ha mixtures of picloram and 2, 4-D applied as foliar spray) and Tordon 225 at 2:2 lb/A (0.9:0.9 kg/0.4

ha) concentration were nearly as effective as Tordon 225 at the heavier application noted above.

Most recent herbicide trials for control of oak have not included Gambel oak, but have involved several species that are morphologically and/or ecologically similar to that species. Work has continued with picloram, but primary emphasis has centered on tebuthiuron (a urea type herbicide sometimes marketed as Spike or Graslan), karbutilate [classified as either a carbamate or urea type herbicides, but with herbicidal properties more like the latter according to Klingman and others (1982)], and buthidazole (an organic herbicide). Working with Q. turbinella in Arizona, Davis and others (1980) tentatively concluded after two growing seasons that "tebuthiuron was the most effective herbicide against shrub live oak, followed in decreasing order by buthidazole, karbutilate, and picloram". All were applied to soil in granular form. At 2.0 lb a.i./A (0.9 kg/0.4 ha) applied in summer, tebuthiuron was over twice as effective (84 percent kill of one year old fire sprouts) as buthidazole at 2.0 lb a.i./A (0.9 kg/0.4 ha) and equally as effective as 8.0 lb a.i./A (3.6 kg/0.4 ha) of karbutilate or 8.0 lb a.i./A of picloram. Summer applications of tebuthiuron to mature oakbrush at a rate of 2.0/lb/A (0.9 kg/0.4 ha) were three times as effective (62 percent stem kill) as karbutilate at the same rate of application. Buthidazole and picloram killed no mature stems at 8.0 lb a.i./A (3.6 kg/0.4 ha) whether applied in summer or winter. Davis and others (1980) suggested that a prescribed burn over mature oak stands followed by soil-applied herbicide treatment of one-year-old fire sprouts would reduce the amount of herbicide needed for equivalent levels of control. No clear pattern was discernible relative to the

effectiveness of summer versus winter applications of the four herbicides tested: tebuthiuron was most effective in summer applications in Arizona, but karbutilate usually performed best when applied in winter.

Davis and Gottfried (1981) noted that Gambel oak was known to be sensitive to soil applied tebuthiuron, but they presented no data. Those authors observed poor response of mature Gambel oak (2 percent kill) to soil applications of picloram at a rate of 6.0 lb a. i./A(2.7 kg/0.4 ha) in Arizona.

Scifres and others (1981) demonstrated that in Texas tebuthiuron applied to soil in the spring at a rate of 2.47 lb/A (2.2 kg a.i./ha) gave 99 percent control of blackjack oak (Q. marilandica), post oak (Q. stellata), and water oak (Q. nigra) three years after treatment. The first two species are similar to Gambel oak in both growth form and ecology. More recently in Texas, Jacoby and others (1983) reported that tebuthiuron gave good control over sand shinnery oak (Q. havardii), a species known to hybridize with Gambel oak and to occupy similar habitats. Tebuthiuron applied at 1.12 or 1.23 lb/A (1.0 or 1.1 kg a.i./ha) killed all mature trees at two sites and gave almost complete control of sprouts for at least 30 months. Tebuthiuron apparently has no deleterious effects on grasses (annual or perennial) at rates normally effective against oak, but its effects on forbs and a wide variety of shrubs other than oak is lethal or at least suppressive (Jacoby and others 1983). Tebuthiuron may remain active in soil for over 12 months even after pellets have dissolved and washed into the soil (Klingman and others 1982), but the effects on forbs appeared to be gone after 15 months or so in the study of Jacoby and others (1983).

The relatively long active life of tebuthiuron in the environment has the potential for serious problems should runoff from treated areas be used for irrigation. Davis (1981) investigated the degree to which tebuthiruon accumulated in runoff from a treated watershed in Arizona. Tebuthiuron had been applied at a rate of 4.0 lb a.i./A (1.8 kg/0.4 ha) in pellets having 20 percent by weight active ingredients. Stream water from the treated watershed was analyzed for the herbicide for 16 months after treatment. Rainfall was unusually heavy during the period of analysis [over 61 in (155 cm) precipitation] yet less than 0.7 percent of the applied herbicide found its way into the stream. Herbicide concentrations in the water never exceeded 0.01 ppm, and none could be detected in the stream after the 18th day following treatment. The herbicide is not considered to be toxic to farm animals or fish (Klingman and others 1982).

The success of tebuthiuron against other oak species suggests that it should be considered for future herbicide trials with Gambel oak. As with all soil applied herbicides, treatments will be most effective on coarse textured and highly permeable soils and in regions where precipitation is sufficient to quickly dissolve pellets and carry the chemical into the soil (U.S. Forest Service 1980).

Engle and others (1983) argued that since Gambel oak had not been controlled completely at economically acceptable rates of application by any herbicide, managers should shift their emphasis from local elimination of the species to investigation of inherent values of the plant and the landscapes that it is a natural dominant on. Their point seems worthy of consideration, since studies demonstrate that the first 25 percent of shrub canopy coverage is the most detrimental to

understory production (Kennedy 1971, Jacoby and others 1983). Thus any sprouting after treatment quickly erodes forage increases arising from that treatment. Furthermore, gains in runoff water achieved by destruction of mature oak stems is lost within three years, if those stems sprout (Tew 1967, Marquiss 1972). In any event, managers should carefully weight the economics of converting oak woodland to herbland for improvement of either forage or water production. Such analysis will require current estimates of costs of herbicides and their application and of grazing animal carrying capacity and water production of the site before and after treatment and monetary value of each resource. The expected longevity of the improved carrying capacity or water yield is also needed for economic evaluation of alternatives. Gaylor (1982) has provided a convenient format for predicting net profit or loss per unit area per year when such facts are known.

Steinhoff (1978) categorized the response of wildlife species to chemical control of oak in Colorado. Only 3 of his 7 Gambel oak associations had more than 2 species of wildlife rated. In his oak-serviceberry - Oregon grape association, oak-serviceberry association, and the pure oak type, 22 wildlife species were rated: of those, only 4 were rated as intolerant to chemical control of oak. Intolerant species were the Ferruginous Hawk, Great Horned Owl, Green-tailed Towhee, and the Lesser Goldfinch.

As with fire, Pearl (1965) felt that conventional herbicide treatments should be rejected because of adverse impacts on scenic, wildlife, soil, and other resource values. There is also resistance to the use of some herbicides (notably 2, 4, 5-T) because of alleged adverse affects on human health (Smith 1979).

Mechanical Manipulation

Mechanical treatments of Gambel oak involve the use of machinery to physically break down the brush. The more common treatments include anchor chaining, brush raking, dozing, roller chopping, and root plowing. Of these, twice-over anchor chaining is considered by many workers as the best treatment for preparing oak stands for reseeding to herbs (Anon. 1966, Marquiss 1971, Plummer and others 1966 and 1968, and Davis and others 1973 and 1975).

Because of prolific sprouting after mechanical treatments, a good follow-up program is needed to control oak regrowth (Marquiss 1971). Many authors have felt that a quick establishment of competitive herbs is an effective way to do this (Anon. 1966). Plummer and others (1966, 1968, 1970) reported that seeding with smooth brome, intermediate wheatgrass and crested wheatgrass had been effective in retarding oak regrowth and had increased deer use from 15 to 65 deer days per acre (160.6 days/ha). Price (1938) showed favorable results when mountain brome, smooth brome, and crested wheatgrass were used. He also reported heavy deer use on treated areas. Plummer and others (1966) and Plummer and others (1970) recommend reseeding with smooth brome, intermediate wheatgrass, and fairway crested wheatgrass. They stated that browsing by both deer and cattle supplemented competition from grasses in keeping oak within reach of grazing animals. Forsling and Dayton (1931) listed many species that can be seeded into oak stands as well as the general environmental requirements of each. They also suggested mechanical methods for the reseeding task. Plummer and others (1968) listed several seed mixtures that do well in different mountain brush types.

Bleich and Holl (1982) provided a general discussion of the response of mule deer to the proportion and pattern of brush and open patches in the chaparral types of California. Many of their conclusions seem applicable to design of mechanical treatments in Gambel oak stands. They concluded that the ratio of brush to open foraging areas is optimal for mule deer at about 1:9. Brush patches should be about 10 ha in size to be useful as escape cover and should be well distributed throughout the foraging areas. Bleich and Holl (1982) also gave comparative costs for controlling brush in California by means of mechanical, chemical hand removal, burning and grazing methods.

Because goats consume buds and leaves of Gambel oak, heavy stocking with goats after removal of top growth of oak is recommended as an effective follow-up treatment to control sprouting (Davis and others 1973, 1975). Chapline (1919) and Nastis and Malecheck (1981) also considered oakbrush to be acceptable forage for goats. Goats are thus potentially capable of efficiently converting oakbrush to red meat and may be able to extend the economically profitable life of oak stands treated to enhance forage production. Goats in combination with cattle could significantly increase the carrying capacity of many oak dominated rangelands (Davis and others 1975 and Nastis and Malecheck 1981). Studies suggest that goats will consume considerable browse even when an abundance of palatable grass is available (Martin and Huss 1981). Knipe (1982) warned, however, that Angora goats relished young grass and could be detrimental in the management scheme if the objective was to suppress oak in order to enhance success of interseeded forage grasses.

Recent changes in the energy situation in the United States require a reevaluation of the values of Gambel oak as fuelwood. The species

grows in extensive stands close to many population centers. On gentler slopes, oak could supply considerable fuelwood without adverse impacts on the environment. In such situations, stands could be opened up for grazing domestic livestock or big game by harvesting fuelwood. As noted earlier, the species' wood has a very high energy content per unit volume. Fuelwood harvests could achieve roughly the same objective as burning, herbicides, or other mechanical manipulations so far as range forage production is concerned. In addition, revenue for sale of oak fuelwood could partially or completely defray cost of treatments to enhance forage production in that community.

Toland (1982) discussed the potential for using brush types structurally similar to the Gambel oak type for energy. He envisioned a future time when sprouting brush types would be harvested with chippers that would remove top growth without destroying roots. Chips could be compressed into small cubes or logs that could be sold directly, gasified, pyrolyzed or used to generate electricity. He called for development of harvesters that could work terrain of up to 30 percent slope without serious soil disturbance. He noted that most native woods produced emissions on burning that were so low in oxides of sulfur and nitrogen that emission control devices would not be needed for their removal.

Escalating fuel costs many eventually make it possible to manage more productive clones of Gambel oak on certain sites for fuelwood as the primary product. However, fuelwood production would probably not be an acceptable management option on a large percentage of the land dominated by this oak. Mechanical treatments, fire or herbicides will probably remain more desirable management alternatives on steep (over

30 percent) slopes, sites where wood production can confidently be expected to be low for environmental or genetic reasons, and sites far removed from potential markets.

Mechanical treatments are referred to as "cutting" by Steinhoff (1978). He rated associated animals in seven Gambel oak associations of Colorado as intolerant or tolerant of cutting. He found that roughly a quarter of the animal species could be expected to be intolerant of cutting, and three-fourths to be tolerant.

Pearl (1965) rejected mechanical treatments because of adverse impacts on scenic, wildlife, soil, or economic values in Gambel oak vegetative types.

Water Production and Management

Although several studies treat the water relations of Gambel oak as a species (Tew 1966, 1967, 1969; Marquiss 1972), few studies consider the yield and hydrodynamics of watersheds where Gambel oak is a major species. Croft (1944) has documented the water relations of Whipple Basin in the northern Wasatch Mountains of Utah, a watershed dominated by Gambel oak. He showed that precipitation on Whipple Drainage averaged about 31 in (78.7 cm): total annual discharge was equivalent to approximately 10.5 in (26.7 cm) per unit surface area. Accordingly, that watershed released about one-third of the annual precipitation as surface runoff. Since average elevation on the watershed was about 7,500 ft (2,286 m), the area was above average elevation for the Gambel oakbrush vegetational type and probably received more precipitation than the average oakbrush stand. As Branson and others (1972) showed, watershed runoff as a proportion of total precipitation is closely correlated with total amount of precipitation. Accordingly, we would

expect most oakbrush watersheds to be less efficient that Whipple Drainage in generation of surface flow. Dortignac (1956) does not consider Gambel oak in his review of Southwestern watersheds, but he does list ponderosa pine which would occur at about the same elevation as oakbrush in the area studied. He considered that the average ponderosa pine-dominated watershed would yield about 17 percent of the annual precipitation as runoff. Since a larger portion of the annual precipitation at Whipple Drainage would accumulate as winter snow in northern Utah than in the ponderosa pine zone of the deep Southwest, we would expect a greater proportion of the total precipitation to appear as streamflow in Utah, but the water yield efficiency observed by Croft (1944) for Whippple Drainage is probably greater than could be expected from most Gambel oak-dominated watersheds even in northern Utah.

Grover and others (1970) developed a theoretical model for predicting water yield increases when deep rooted woody species are replaced by herbaceous cover in central Utah. Their model predicted that replacement of Gambel oak with herbs would increase water yield by from about .9 to 5.4 in (2.3 to 13.7 cm) per year as one moved from the lower to the upper elevational limits of the oakbrush zone in Ephraim Canyon, Sanpete County.

Tew (1966) demonstrated that a Gambel oak stand with 65 ft^2 of basal aread per acres (15 m^2/ hectare) used 11 to 13 in (28 to 33 cm) of water per year from the upper 8 ft (1.2 to 2.4m) depth zone. Tew (1967, 1969) showed that Gambel oak depleted about 3.0 in (7.6 cm) more water from the soil than perennial range grasses on the same site. Removal of oak followed by sprouting resulted in a return to precut water use rates in 3 years.

Reanlysis of Marquiss (1972) data suggest that removal of oak from southwestern Colorado rangelands would leave at least 1.4 in (3.6 cm) of additional water per year in the surface 5 ft (151 cm) of soil [estimate based on percent gravimetric water in five 1.0 ft (30.5 cm) deep soil layers averaged over the entire growing season and across 4 years with an assumption of a dry weight of 2 million pounds (9.072 x 10^5 kg) per 0.5 ft (15.2 cm) layer of soil per acre (0.4 ha)]. The estimate is probably conservative, since the value employed for water use of oak was an average of control and sprout clones and samples were taken from only the surface 5 ft of soil even though oak is known to draw water from depths greater than that (Tew 1969). Marquiss' (1972) results support those of Tew (1969) in that after four seasons of regrowth, water depletion was essentially equal under control and sprout populations of oak. Parker (1975) concurred that Gambel oak is a heavy consumer of water. It does, however, provide excellent control over soil erosion on the watersheds that it dominates (Petersen 1954).

General Comments

Diseases and Pests

Oak seems reasonably free of pests and diseases that have a high probability of eventually killing the plant (or at least aboveground parts) at any given site. Thus Gambel oak management in central and northern Utah will usually not be complicated by the intervention of serious pests and/or diseases. Pests and disease are discussed in detail in the review which is part of this final report.

Development of a Type Classification System

Any management scheme is simplified and rendered more effective if system variations relevant to management are known and geographically mapped. Steinhoff (1978) has defined 7 habitat-types for Gambel oak in southwestern Colorado (see Table 4 of the literature review). Four of those oak habitat-types can be expected in central and northern Utah: 1) Pinyon-Juniper-oak, 2) Oak-Serviceberry-Oregon Grape, 3) Oak-Serviceberry, and 4) pure Oak. It seems likely that those habitat-types will have management value in this area. It also seems likely that other habitat-types exist in Utah (e.g., Oak-Rocky Mt. Juniper, Oak-Snowberry, and Oak-Mt. Lover). A research project to identify and define characteristics of existing habitat-types in the area seems justified. Any such project should require the management implications of type characteristics be identified and discussed.

Development of a Management Plan

It seems impossible for me as an outsider to develop a finished management plan that will be immediately usable by the Forest Service. There are so many legal, personnel, funding and time constraints that must affect a management plan but that are unknown to an outsider, that he cannot deliver a usable plan without coauthorship by some Forest Service employee or employees. I am familiar with the oak resource and the available management alternatives and both topics are discussed in considerable detail in both the literature review and this report, but an operational management plan must be so uniquely fitted to the organization that will use it that an outsider cannot draft it without a great deal of input from that organization!

Recommendations

1. A 50-60 year rotational cycle of rejuvenation should be initiated on all oak dominated lands where stems have elevated foliage beyond the reach of big game animals. Low stature stands wherever they occur should be excluded from treatment unless considerations other than forage and fuelwood production demand attention.
2. Fuelwood harvesting should be the preferred management tool for stand rejuvenation on sites within easy reach of existing roads and where slopes are relatively gentle ($<15\%$). Such stands must have stems with average diameters at breast height of over 3.0 in.

3. Treatment should be applied to the best quality sites first (i.e., sites that have gentle slopes, deep, fertile soils, good water relations, and warm microclimates), since harvests will be greatest on such sites and harvesting costs will be least per unit volume.
4. Steep slopes and areas far removed from potential markets that require rejuvenation treatment should be evaluated for possible controlled burning.
5. Where prior abusive grazing has depleted oak understories of desirable forage plants, aerial seeding of adapted, high quality plants should be considered. If sites are so seeded, the seeding should preceed the rejuvenation treatment by at least 5 years.
6. All oak dominated lands on the Forest should be habitat-typed.

LITERATURE CITED

See literature review for full citations.